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Applying Least Mean Square Method to Improve Performance of PV MPPT Algorithm

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Abstract

Solar photovoltaic (PV) system shows a non-linear current (I) –voltage (V) characteristics, which depends on the surrounding environment factors, such as irradiance, temperature, and the wind. Solar PV system, with current (I) - voltage (V) and power (P) - Voltage (V) characteristics, specifies a unique operating point at where the possible maximum power point (MPP) is delivered. At the MPP, the PV array operates at maximum power efficiency. In order to continuously harvest maximum power at any point of time from solar PV modules, a good MPPT algorithms need to be employed. Currently, due to its simplicity and easy implementation, Perturb and Observe (P&O) algorithms are the most commonly used MPPT control method in the PV systems but it has a drawback at suddenly varying environment situations, due to constant step size. In this paper, to overcome the difficulties of the fast changing environment and suddenly changing the power of PV array due to constant step size in the P&O algorithm, least mean Square (LMS) methods is proposed together with P&O MPPT algorithm which is superior to traditional P&O MPPT. PV output power is predicted using LMS method to improve the tracking speed and deduce the possibility of misjudgment of increasing and decreasing the PV output. Simulation results shows that the proposed MPPT technique can track the MPP accurately as well as its dynamic response is very fast in response to the change of environmental parameters in comparison with the conventional P&O MPPT algorithm, and improves system performance.

Keyword: Photovoltaic Systems, Maximum Power Point Tracking (MPPT),
Perturbation and Observation (P&O), Least Mean Square (LMS) Algorithm

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Introduction

Solar PV power system is a power system designed to supply usable solar power by means of Photovoltaic as renewable energy sources. Nowadays, many renewable sources are available, among these; solar energy have become widely utilized.

Solar energy obtained from a solar PV cell is fluctuating in nature affected by external environment conditions like solar irradiance and cell temperature. The amount of power extracted from PV system is a function of the PV module voltage and current. The operating

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point of the PV generator is located at the intersection of it's current (I) and voltage (V) point at where the possible maximum power point (MPP) is delivered. At the MPP, the PV generator operates at maximum power efficiency. I-V characteristics of the PV system are nonlinear and will change with the external environment like irradiance and temperature of a PV cell, so the power output is also changing. MPPT algorithms regulate output power of PV array automatically by to obtain the maximum power output under given temperature and Irradiance.

Maximum power point trackers (MPPT) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency, [1]. Thus, an MPPT can minimize the overall system cost. MPPTs find and maintain operation at the maximum power point, using an MPPT algorithm. There are many such algorithms have been proposed, [2-4]. Presently, numerous techniques have been proposed so far for realizing the MPP. These MPPT methods are different in complexity, sensors requirement, convergence speed, cost implementation, effectiveness, and popularity. Among them Perturb and Observe (P&O) method [5], constant voltage method and the incremental conductance are most common and widely used. The constant voltage is the simplest of them and the P&O MPPT algorithms are mostly used, due to its ease of implementation. A drawback of P&O MPPT technique is that. At steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy and the system accuracy is low. These conventional MPPT methods face a difficult in tracking the MPP in fast changing environment.

To overcome the difficulties of commonly used MPPT methods of P&O algorithms we previously proposed, perturb and observe algorithm with adding the duty ratio perturbation [6] to obtain the MPP. It means that the duty ratio is using directly as the control parameters for MPPT controller in the P&O algorithm. In this algorithm, the operating point has initialized to 50% duty ratio. If the power increases, the algorithms continue to perturb the system in the same direction otherwise in the opposite direction with a chosen duty step size. Applying duty cycle in conventional P&O MPPT algorithm, we can obtain the performance improvements in terms of MPP tracking accuracy and deviation reduction.

In this paper, to overcome the difficulties of the fast changing environment and suddenly changing the power of PV array due to constant step size in the P&O algorithm, least mean square (LMS) methods is proposed together with P&O MPPT algorithm. LMS algorithm is easy to implement as its weight adaptation step-size fixed, [7]. However, LMS algorithm has a simple structure but its main disadvantage is its slow convergence in case of a large range of Eigenvalue of the regression covariance matrix [8]. This proposed MPPT can track the MPP not only accurately but also its dynamic response is very fast in response to the change of environmental parameters in comparison with the conventional P&O MPPT algorithm and previously proposed stepping duty cycle to P&O MPPT algorithm. This newly proposed LMS based MPPT method is simpler, just using the stepping duty size in reference to the error calculated by the LMS methods [14].

This paper is organized as follows; section 2 described perturbation and observation technique. Mathematical description of solar PV cell model and description of DC-DC boost converter are presented in Section 3. MPPT algorithms and proposed technique are described in Section 4. Experimental setup and simulation result are described in Section 5. Finally, the conclusion is stated in Section 6.

2. Perturbation and Observation (P&O)

P&O method is one of the most commonly used MPPT algorithms for tracking the maximum power due to its simplicity. This algorithm works repeatedly perturbs on the input by a fixed step. Then, PV power output is compared with that of the previous perturbation cycle. If the power increased, the perturbation goes in the same direction in the next perturbation cycle; otherwise, the perturbation direction should be in reserved [6] [9].

This method has a wrong estimation when the atmospheric conditions change rapidly, due to its constant step size, which may lead to the power loss of the PV array.

3. Numerical Background and Models

PV cell modeling needs an equivalent circuit with exponential characteristics and it could be achieved from a diode model. This model accepts the solar irradiance and the temperature as input parameters and produces current as an output. Among these mathematical modeling, a single diode is most commonly used due to its less complexity, [10]. Hence, for the most analytical and design purposes, single diode equivalent circuit for PV system as shown in figure 1 is used. The equation of the single diode equivalent circuit for PV model is [14]

$$I = I_{PH} - I_d\left[e^{\frac{q(V+IR_{se})}{AKT}} - 1\right] - \frac{(V+IR_{SE})}{R_{SH}} \quad (1)$$

Where,

$$I_{PH} = I_{SC} * \frac{I_{RR}}{1000} * [1 + (T_{CELL} - T_{REF}) * K] \quad (2)$$

The I_{PH} is the photo-generated current by a solar cell, I_d is the saturation current diode, and is shunt resistance current. R_{SH} and R_{SE} are the shunt resistance and series resistance respectively. The shape factor is A, and K is the Boltzmann constant (1.38064852(79) $\times 10^{-23}$ $J \cdot K^{-1}$). The q is the electron charge (1.60217662 $\times$ 10^{-19} coulombs) and V is the terminal voltage of the cell.

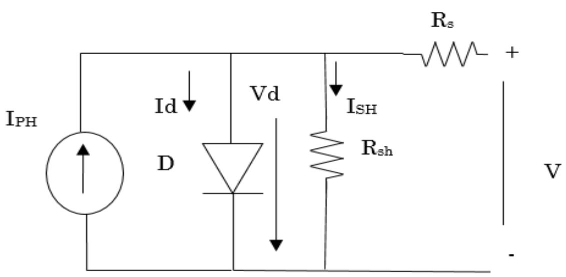

Fig. 1. Single diode solar PV equivalent cell model

The studied PV system is a stand-alone energy conversion as shown in figure 2 and detailed with proposed LMS MPPT algorithms shown in figure 4. It consists of PV arrays with DC/DC boost converter. The DC/DC Boost converter is used to for PV power generation, [12]. DC-to-DC power boost converter steps up voltage (V) while stepping down current (I) from its PV input to its load power output.

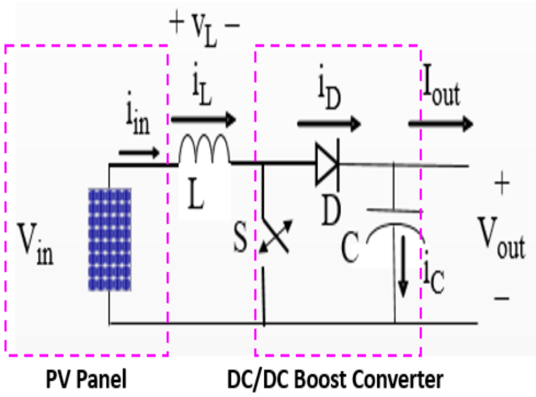

Fig. 2. Circuit Diagram of Boost Converter with PV

In figure 2, i_{in} is the photo-generated current by a solar cell, i_d is the diode current from Diode D, and i_c is capacitance current. i_L is inductor current from inductor L and S is the power switch which modulates the power from PV input to load output in terms of the varying duty cycles and V_{in} and V_{out} are the solar PV voltage output and converter voltage output respectively.

4. Proposed LMS based MPPT Algorithm

A various number of different MPPT control algorithms has been proposed, including the P&O algorithms. Among the algorithms, P&O and Incremental Conductance (INC) algorithms are widely used due to its simplicity, easy and low-cost implementation.

The Conventional P&O algorithm uses voltage value as the control parameter in addition to proportional-integral (PI) controller. The used PI controller is tuned while operating the system at a constant voltage equal to the PV output voltage in standard test condition (STC). This algorithm perturbs the operating point by increasing or decreasing voltage values and measures the PV output power before and after the perturbation.

The simplicity of the LMS algorithm, [11,14,15,16] and ease of implementation means that it is the best choice for many real-time systems. In this paper, simulation model and the proposed algorithm using LMS Methods in the conventional P&O algorithm are shown in the following figure 3 and 5 respectively. Here, the proposed method including LMS technique performs an additional measurement of power differences by calculating the error. Firstly, we Estimate the error by using the calculate power and predicted power i.e.

$$e(n) = y(n) - d(n) \tag{3}$$

Where y (n) and d (n) are calculated and predicted power respectively. By setting the training factor, here we have to choose very carefully so that weighting vector can converged. Then we used the LMS algorithms; to update the error by updating the weighting coefficient

$$\overrightarrow{w}(n+1) = \vec{w}(n) + 2.\mu\ .e(n).\vec{x}(n) \tag{4}$$

We mapped the error value every time and set the duty step size according to the changed error. Initially, we set the duty cycle value to 0.5, taking a mean value between 0 and 1. After that, we continuously checked the error value, if $e(n)>0$ that showed, measured power is greater than the predicted power. So the perturbation in the positive direction, then we mapped the error with limit. If error value is small, that shows there is small fluctuation in the power so increased the duty value with small step size, $1 = \langle e(n) \rangle 5$. Then increased the duty value with 0.002 i.e. $(n) = D(n) + 0.02$, Otherwise increased with big duty size $D(n) = D(n) + 0.05$. It can track the MPP with less deviation in highly fluctuating environment.

As it seen on the figure 5 below, the changes in power, i.e. difference between the measured and predicted power gave the error and based on LMS, power value is continuously mapped by small amount step sizes to track the certain fluctuation in PV outputs. Here, if the error is high then the duty value i.e. stepping value also increased with big values from the initially defined value. Therefore, in this proposed LMS based MPPT, we stepping the duty cycle size according to the error updated by original LMS algorithms. First, we check the error is either positive of negative, then checking the error range with a high difference or low we define the stepping duty cycle size that will help to recover the MPP value in rapidly changing environment condition. In addition, this generated duty cycle control the DC-DC

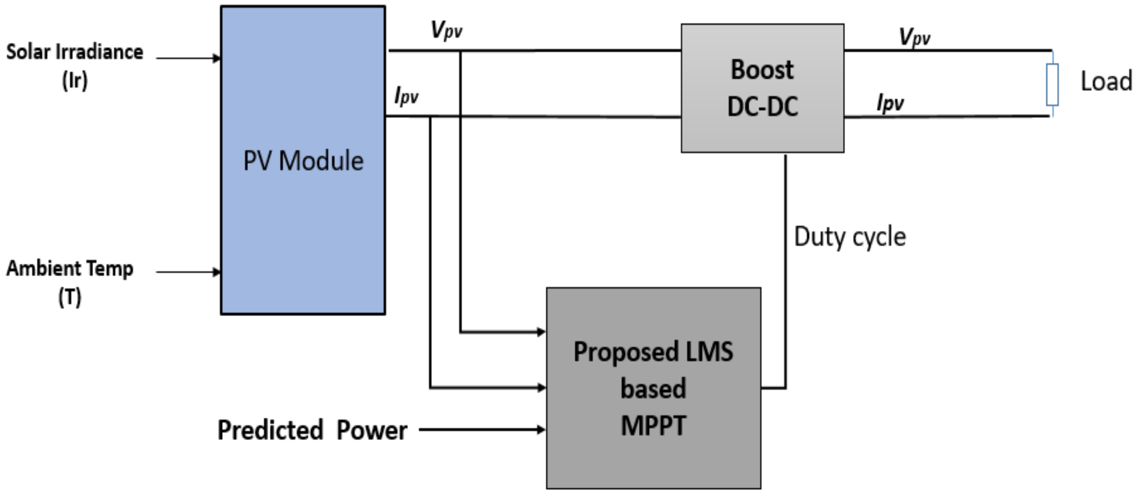

Fig. 3. Simulation Model with DC-DC converter

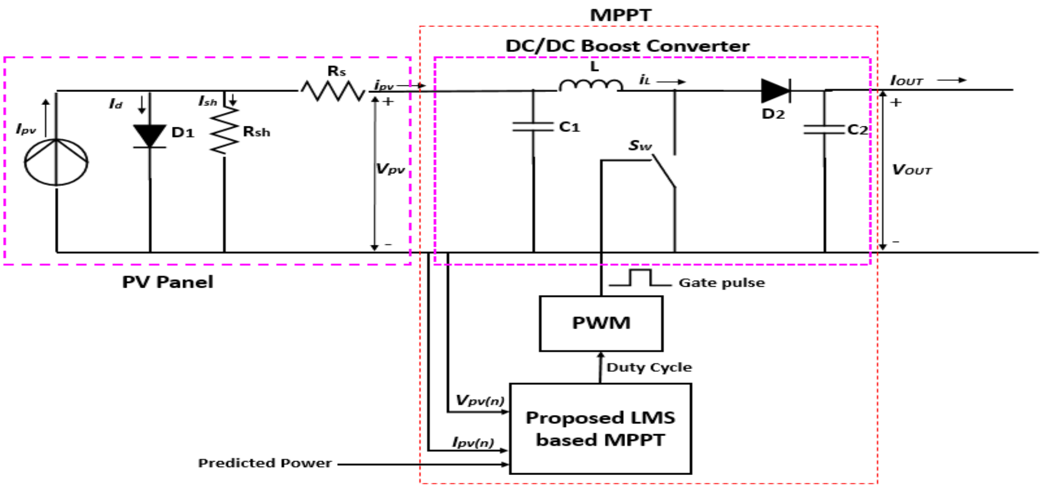

Fig. 4. Detailed Simulation Model with DC-DC converter

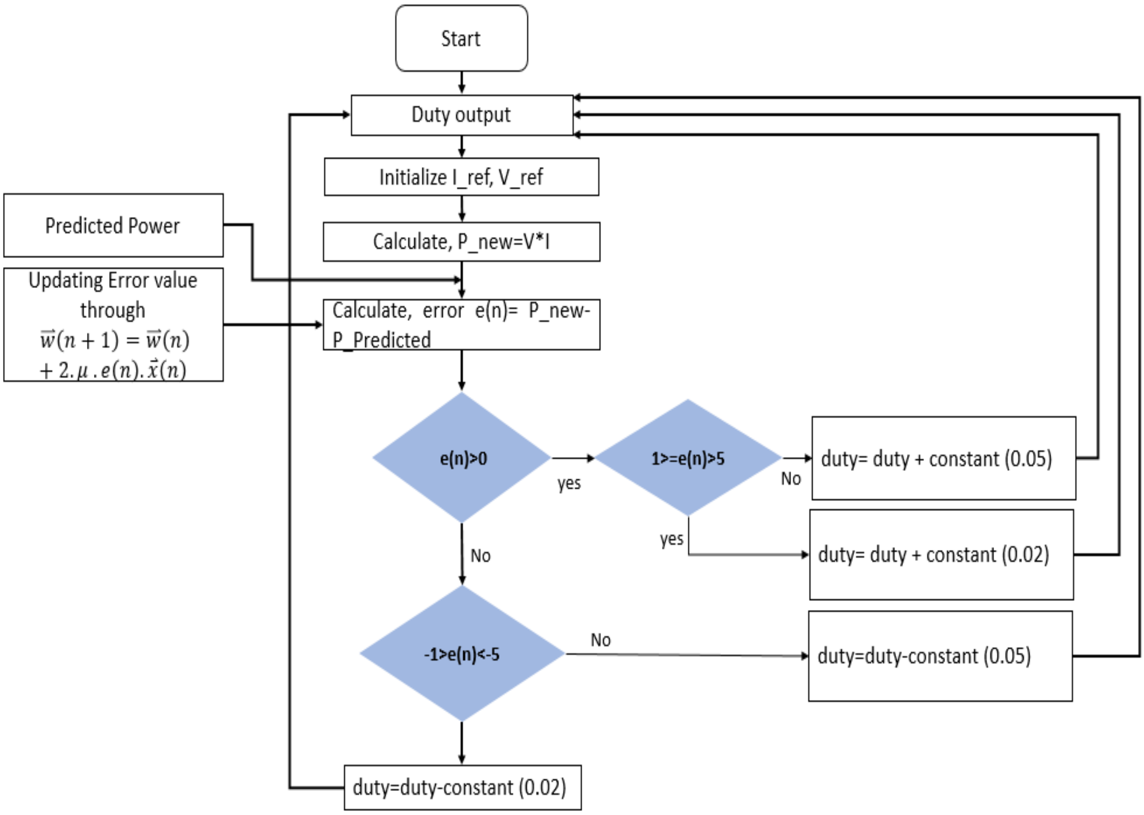

Fig. 5. Flowchart of LMS based MPPT Algorithms

converter constant voltage output to track the MPP effectively. [14,15,16]

5. Simulation Results and Comparison

For the results verification, firstly the PV module of 100wp capacity, monocrystalline power output has been chosen for the modeling and analysis. The simulated I-V and P-V characteristics of the 100wp capacity module have generated and tested. Fig.6 shows the comparison of PV power output between the newly proposed LMS based MPPT algorithms with a P&O algorithm with duty cycle stepping and with voltage value i.e. conventional method. It clearly shows that the

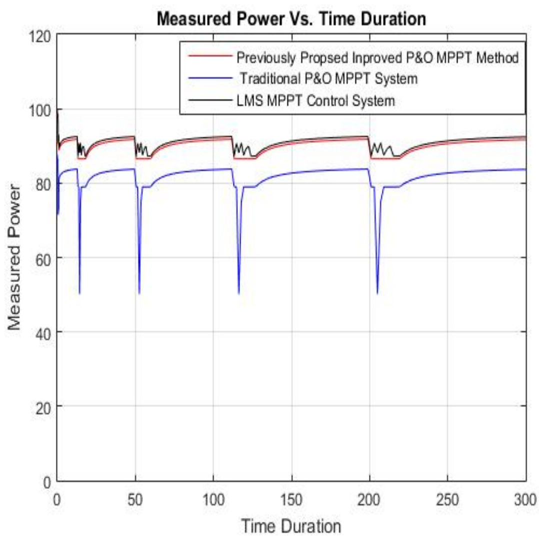

Fig. 6. PV output power comparison of P&O with LMS based stepping duty cycles and conventional parameter

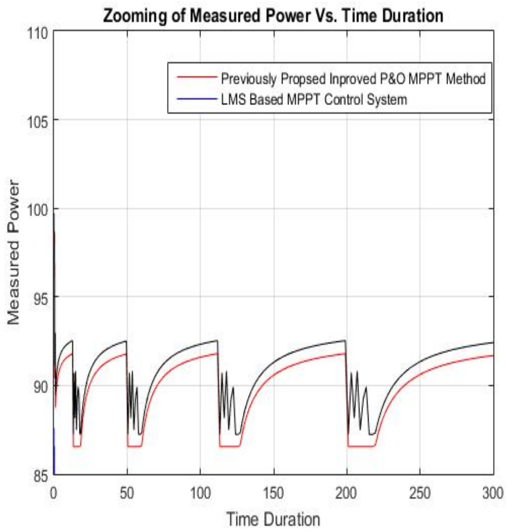

Fig. 7. Zooming view of PV output power comparison of previously proposed improved P&O with LMS based MPPT algorithms.

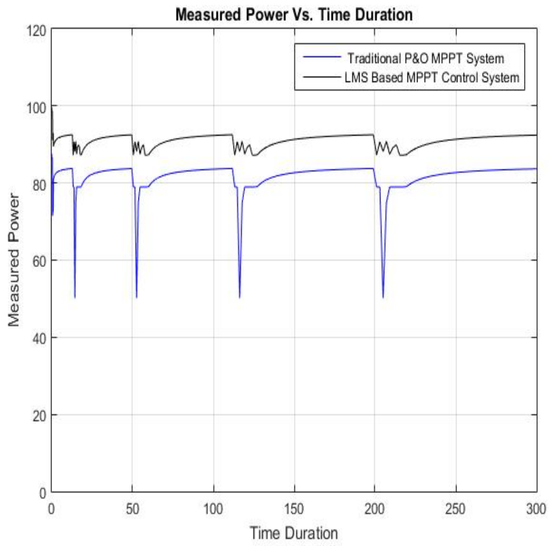

Fig. 8. PV output power comparison LMS based stepping duty cycles and conventional parameter.

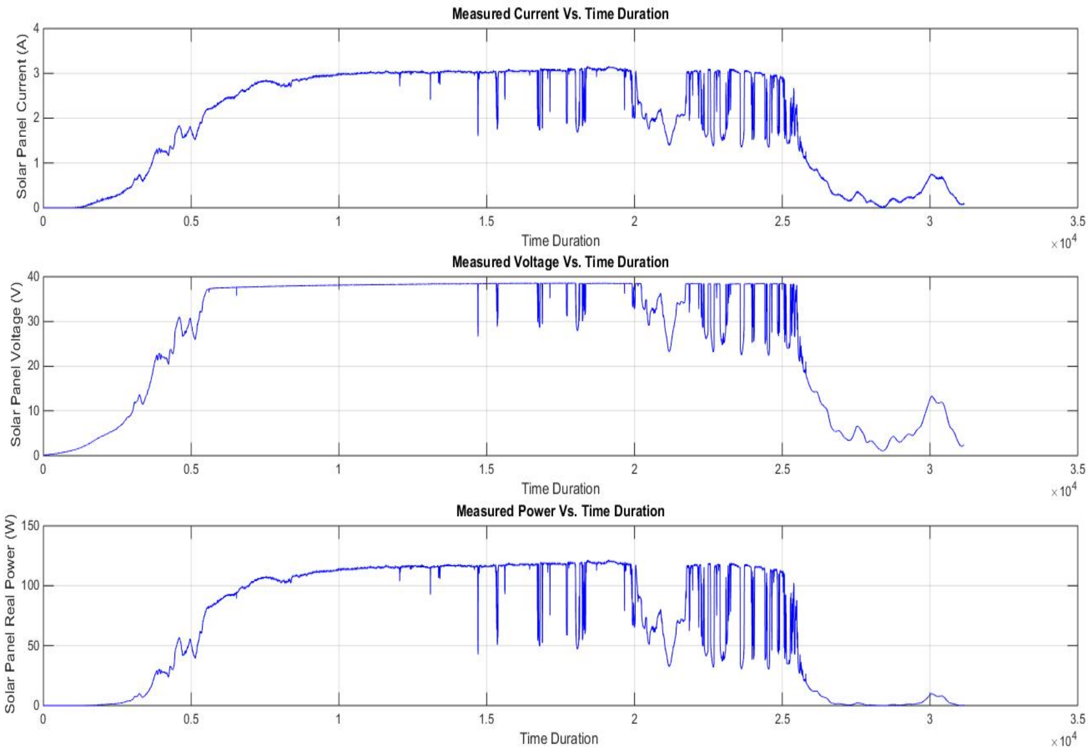

Fig. 9. PV array output power from a SANYO 200Wp photovoltaic module that installed at the Hae-Nam, Korea

differences in power outputs. The black lines (the case using LMS based) in Fig.6 shows generating higher output powers with less deviation. It means that less fluctuating is happened for tracking MPP if we use LMS based stepping duty cycle as the control parameter in the P&O algorithm. Thus this experimental result shows that, with implementing the LMS based perturbation technique at the P&O MPPT algorithms, it has the better time response and more performance that is accurate.

From the figure 7, we can see the differences of power outputs in a limited range, which clearly shows the increased power by using LMS based MPPT control comparison of previously proposed improved P&O with LMS based MPPT algorithms. In figure 8 there is PV output power comparison LMS based stepping duty cycles and conventional parameter.

Secondly, the proposed technique validated using an experimental field environmental and electrical parameter from a SANYO 200Wp photovoltaic module, installed at the Hae-Nam, Korea. The detailed was in [13]. In this system, the PV power generation along with climatic data is stored in PC via Internet, and continuously monitored.

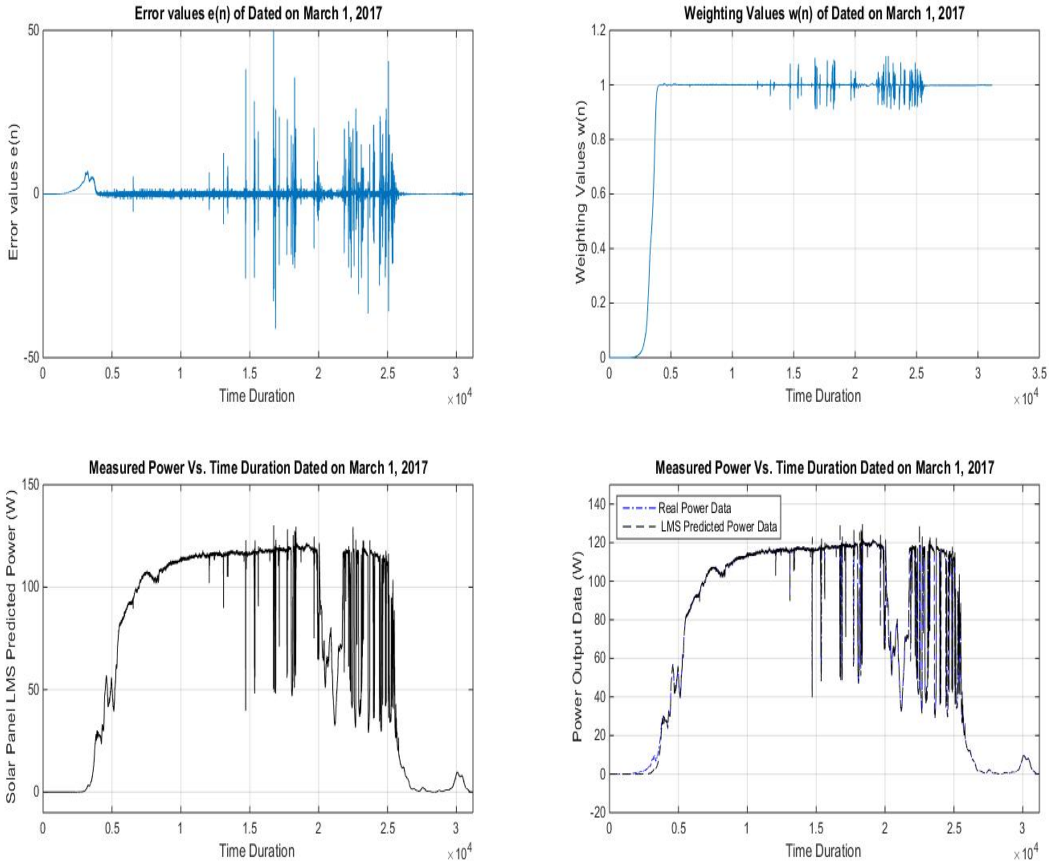

Fig. 10. LMS model output of solar PV data including error, weighting factor, predicted power output and power comparison of real solar power data with LMS based prediction data plot.

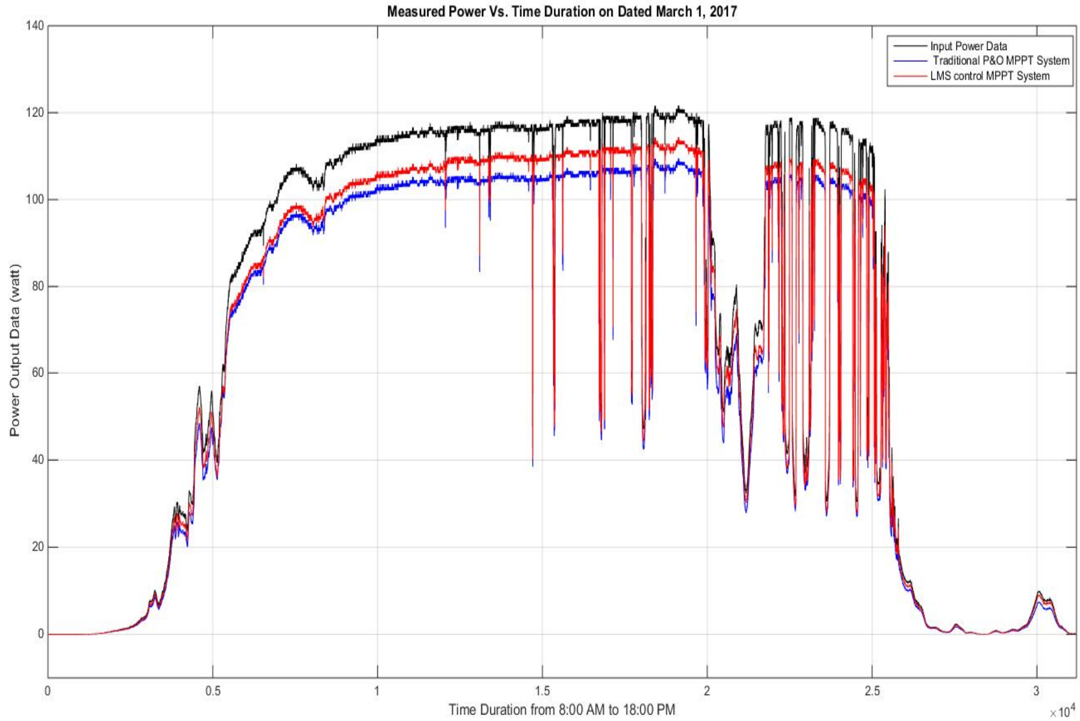

Fig. 11. PV output power comparison of conventional P&O with LMS based MPPT

The data obtained from the experimental site has modeled using the LMS MPPT method. Data have recorded on a sunny day, on dated March 1, 2017, from 8 AM to 18 PM. Figure 9 shows the real PV power data taken from the experimental field site to apply MPPT control. Figure 10 shows the LMS predicted power with error and its converged weighing coefficient clearly. The predicted power of PV array with LMS help the P & O judge the power difference in advance.

In figure 11, there is a comparison of PV power output between the newly proposed LMS based MPPT algorithms with traditional P&O algorithm method together with real power data.

The purpose of this work is to obtain such an experimental comparison between the tradition P&O over newly proposed stepwise P&O and LMS based MPPT algorithms and suggest which MPPT control algorithm is the most

effective on the basis of MPPT efficiency, which is defined as;

$$\eta_{MPPT} = \frac{\int_0^T P_{Actual}(t)dt}{\int_0^T P_{Max}(t)dt} \qquad (5)$$

Where, P_{Actual} is the measured power produced by the PV array under the control of the MPPT, and P_{Max} is the true maximum power of the array that could produce under a given temperature and solar irradiance. The Quantitate comparison between the different algorithms in simulation data and real data are presented in below table 1 and 2 respectively. Where we clearly present average power output by PV array under the different control of the MPPT algorithms and their improved efficiency.

Table 1. Average power output in simulated data case by PV array under the different control of the MPPT algorithms and their improved efficiency

Average Power Output (Watt)			Improved Efficiency Percentage (%) between the traditional and Stepwise P & O MPPT	Improved Efficiency Percentage (%) Between the traditional and LMS based MPPT	Improved Efficiency Percentage (%) Between the Stepwise P & O and LMS based MPPT
Traditional P & O MPPT	Step wise Duty cycle P & O MPPT	MS based MPP			
84.3	90.7	92.8	7.59%	10.08%	2.32%

Table 2. Average power output by PV array in real data case under the LMS MPPT control and Traditional P&O MPPT algorithms and their improved efficiency

Average Power Output (Watt)		Improved Efficiency Percentage (%) Between the traditional P&O and LMS based MPPT
Traditional P&O MPPT	LMS based MPPT	
62.0392	64.5739	4.085%

The performance comparison between the traditional P&O method with the previously proposed stepwise duty cycle P&O and LMS based MPPT method are shown in table 1 and 2 in different cases. In the simulation data case, the efficiency of LMS based MPPT algorithm is about 10.08 % higher than the traditional P&O method. While comparing the traditional P&O method with previously proposed stepwise P&O MPPT method, the efficiency is about 7.59% higher. In addition, LMS based MPPT algorithm 2.32% higher than the previously proposed stepwise P&O MPPT method and the efficiency improved is even better in highly fluctuating irradiance. In the real data case, where we take the whole day data under various temperature and irradiance effect, the efficiency with LMS based MPPT algorithm is about 4.085 % higher than the traditional P&O method.

6. Conclusion

LMS based MPPT algorithm has presented in this paper. Firstly, the characteristics of PV module and a mathematical model has presented to generate simulating data. Then, LMS based MPPT algorithm has proposed with the DC/DC boost converter. This method adds adaptive predict mechanism to predict the output power of PV system. The effectiveness and accuracy of the proposed control system have been verified by both simulation and experimental data. The results obtained from

MATLAB/SIMULINK by implementing proposed LMS based control in the both simulated and real I-V data case show the effective performance in power tracking in high fluctuating condition over the other conventional P&O MPPT control algorithms with better efficiency. This proposed LMS based MPPT is found to be computationally less complex, and effective in tracking MPP of the studied PV system, which is also a great significance in the PV system application.

Acknowledgement

This paper was mainly written by adapting the first author's Master degree thesis which was supervised by the corresponding author [14], and also the similar versions by shorten or summary of the original thesis were published elsewhere conferences [15-16]. Among our publications of the work result subjected to PV with LMS, we are ultimately considering that this version is the deepest and best described research paper.

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